SHUTTLE INDUCED ENVIRONMENT CONTAMINATION MONITOR

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ABSTRACT

The Induced Environment Contamination Monitor (IECM) is a set of ten instruments integrated into a self-contained unit. The IECM is scheduled to fly as part of the Demonstration Flight Instrumentation (DFI) on Shuttle Orbital Flight Tests 1 through 6 and on Spacelabs 1 and 2 as part of the Verification Flight Instrumentation (VFI).

NASA began strong manned mission contamination control efforts for the Skylab mission and, recognizing the possible limiting effects induced contamination might have on sophisticated observational programs planned for the 1980's, committed to an effort to insure that the induced environment would not be a problem.

The purpose of the IECM is to measure the actual environment to determine whether the strict controls placed on the Shuttle system have solved the contamination problem.

The IECM will operate during prelaunch, ascent, on-orbit, descent, and post-landing. The on-orbit measurements are molecular return flux, background spectral intensity, molecular deposition, and optical surface effects. During the other mission phases dew point, humidity, aerosol content, and trace gas will be measured as well as optical surface effects and molecular deposition.

The ten instruments are: Dewpointer, Humidity Monitor, Cascade Impactor, Optical Effects Module, Passive Sample Array, Temperature-Controlled Quartz Crystal Microbalance, Air Sampler, Mass Spectrometer, Camera/Photometer, and Cryogenic Quartz Crystal Microbalance. Each instrument is briefly described, and its measurement limitations are compared to the contamination control requirements.

Efforts are being made to operate the IECM using the Shuttle Remote Manipulator System to directly measure off- and outgassants as well as column densities. This would be accomplished by actually picking up the IECM and moving it about the Shuttle for various measurements.

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1.0 INTRODUCTION

When the decision was made to develop the Space Transportation System (STS) as a universal carrier for manned space science experiments, there was much concern from the scientific community, particularly the astronomers, as to whether the induced particles and gases environment would place limitations on the measurement programs envisioned for the 1980's.[1,2] This concern stimulated a number of activities which include the identification of potential contamination problems, the establishment of upper limits of induced environment tolerable to experimenters, studies to assess the induced environment from current STS design, and recommended changes to achieve the desired background.

Similar concerns were identified during the development of the Skylab Program and prompted a significant research effort to develop an understanding of the various mechanisms by which experiments could be compromised and to establish the technology of contamination abatement through vehicle design and operational procedures. These efforts contributed to the successful operation of most of the Skylab and Apollo Telescope Mount (ATM) experiments. Some measurements of the molecular deposition and scattered light background were made on Skylab which confirmed that many of the precautions taken were

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1. Anon., Final Report of the Space Shuttle Payload Planning Working Groups, Astronomy Volume 1, NASA/Goddard Space Flight Center, Greenbelt, Maryland (May 1973).

2. Space Science Board, Scientific Uses of the Space Shuttle, National Academy of Sciences, Washington, D.C. (1974).

necessary. These measurements and related laboratory work indicate there is still much to be learned concerning the interactions between the spacecraft, the induced atmosphere, and the ambient atmosphere.

As a result of concerns for possible contamination from the induced environment, the Contamination Requirements Definition Group (CRDG), chaired by R. J. Naumann of NASA's Marshall Space Flight Center, set goals for the control of particles and gases that would be emitted by the Space Shuttle.[3] To assure that the goals have been met, the Induced Environment Contamination Monitor (IECM) (Figure 1) was designed to provide verification of particles and gases measurements during ground operation, ascent, on-orbit, descent, and post-landing. These verification measurements are planned for all six Orbiter Flight Tests (OFT's) and for Spacelabs 1 and 2.

Spacelab 1 will provide the opportunity to obtain contamination data from a short-module-plus-pallet configuration. Spacelab 2, which is planned as a pallet-only setup, will provide a comparison between these two basic configurations.

A smaller version of the IECM will be flown on the Long Duration Exposure Facility (LDEF) satellite to obtain contamination data on deployment and retrieval as well as ground handling of large satellite payloads (Figure 2).

2.0 STS CONTAMINATION CONTROL REQUIREMENTS

Contamination control requirements were incorporated into the Space Shuttle Flight and Ground Systems Specification, Volume X,[4] by the Particles

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3. Payload Contamination Control Requirements for Shuttle Transportation System (STS) Induced Environment, STS Payload Contamination Requirements Definition Group Report, NASA/Marshall Space Flight Center, Alabama (July 1975).

4. Space Shuttle Program Level II Program Definition and Requirements, NASA/JSC-07700 Flight and Ground Systems Specification, Volume X, Revision B (August 1975). (This specification will be cited as "Volume X" throughout the remainder of this paper.)

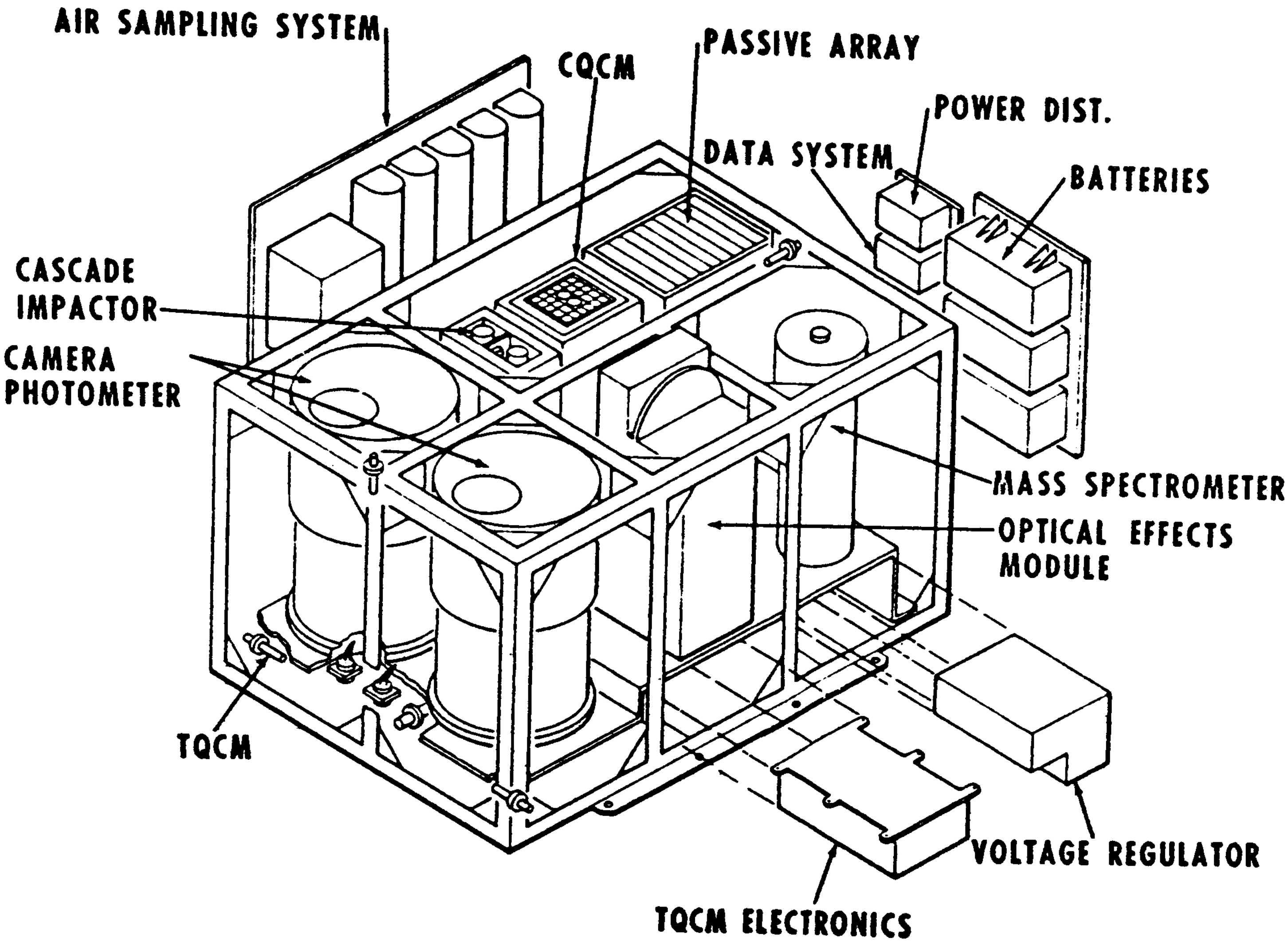

Figure 1. Induced Environment Contamination Monitor, OFT/DFI and Spacelab VFI Unit.

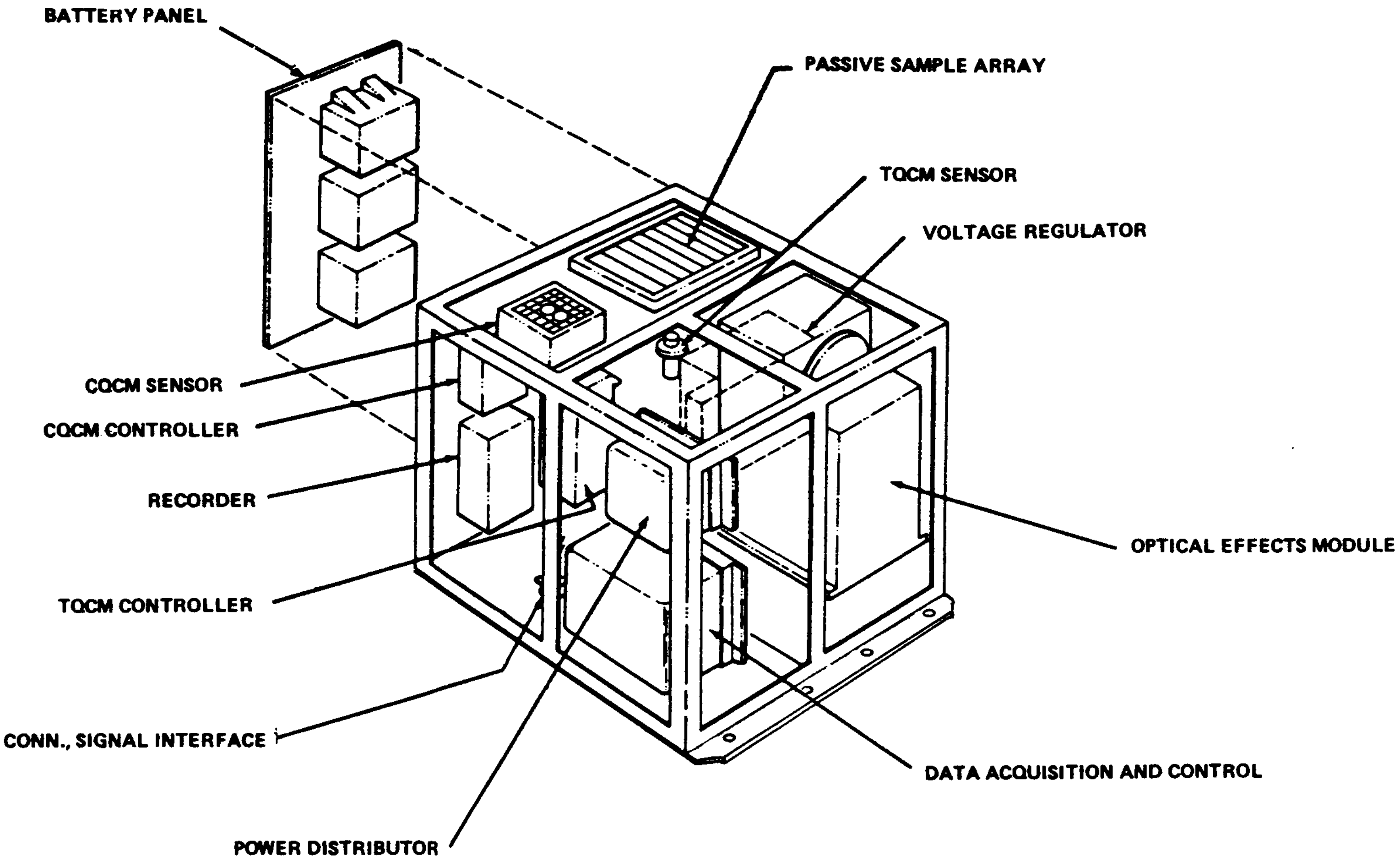

Figure 2. Induced Environment Contamination Monitor — LDEF.

and Gases Control Panel (PGCP) as Shuttle design goals. These specifications were restated in the payload accommodation document, Volume XIV.[5]

The CRDG was established with representatives from user disciplines, each NASA payload center, and the Department of Defense. The CRDG in-depth study for potential payloads established a net requirement for the STS that is similar to the requirements specified in Volume X but is more inclusive and definitive.[3]

During orbital operations, molecules continually leave the spacecraft from leaks, vents, thruster firings, surface desorption, and material outgassing. These gases expand freely and eventually collide with the ambient atmosphere. Their presence forms a tenuous artificial atmosphere around the spacecraft, sometimes referred to as a contamination cloud. This cloud has a molecular column density that on the average is much less than the residual ambient atmosphere at orbital altitudes. The composition, however, is such that the column densities of some species greatly exceed the natural environment. The species of most concern are H_2O, CO_2, CO, H_2, OH, and a variety of silicone and organic polymers. Some of these molecules are of astrophysical interest, and their presence in the induced atmosphere in detectable concentrations is undesirable. Other molecules may have absorption lines that could mask the line to be detected. The spectral resolution to be used in the astronomical observations planned for the Space Shuttle will permit the detection of absorption lines with 0.001 A equivalent line width. With this resolution, a 10^{10} molecule/cm^2 column with a strong transition line in the ultraviolet will be detectable. The preceding species are detectable at 10^{11} to 10^{12} molecules/cm^2. The CRDG requirements for column density are 10^{13} molecules/cm^2 for $N_2 + O_2$, 10^{11} molecules/cm^2 for $H_2O + CO_2$, and 10^{10} molecules/cm^2 for all other

5. Space Shuttle Program Level II Program Definition and Requirements, NASA/JSC-07700, Volume XIV, Revision E (July 1977).

species. The requirement stated in Volume X for H_2O is 10^{12} molecules/cm^2.

Another concern is the deposition of the heavier molecules, particularly the silicones, on optical surfaces. Such molecules become polymerized by the presence of energetic radiation and form a permanent brown film. A thickness of only a few monolayers ($\sim 10^{-7}$ gm/cm^2) is sufficient to begin to cause significant optical degradation in the vacuum ultraviolet, whereas a film of up to 10^{-5} gm/cm^2 is tolerable on infrared optics or on thermal control surfaces.

Most critical optical surfaces must of necessity be shadowed from any portion of the STS by light baffles. Such baffles provide excellent protection against direct line-of-sight transport of molecules leaving an outgassing surface that might otherwise deposit on the critical surface. Some molecules can arrive at a surface protected in this manner by making one or more collisions with other molecules in the contamination cloud or by colliding with an ambient atmospheric molecule. For the expected number densities associated with the STS, collisions with atmospheric molecules will be the dominant return mechanism. For surfaces at ambient temperature ($\sim 300^\circ$K) the CRDG requirement specifies that no more than 10^{-5} gm/cm^2 of material shall deposit during a 30-day mission on an unprotected surface (2 arc sec steradian acceptance) and no more than 10^{-7} gm/cm^2 shall deposit on a surface with 0.1 steradian acceptance angle during a 30-day mission. A layer of 10^{-7} gm/cm^2 should produce less than 1 percent degradation for the expected contaminants over most wavelengths from the far ultraviolet to the far infrared. For cryogenic surfaces there is an additional concern stemming from the large amounts of H_2O in the induced environment which will condense at cryogenic temperatures. The CRDG requirement specifies that such a surface with a 0.1 steradian acceptance angle shall accumulate no more than 10^{-5} gm/cm^2 in a 30-day mission. This requirement is expressed in Volume X in terms of a limit of 10^{12} molecules/cm^2/sec backscatter flux. This flux would result in a total molecular deposition of 4.1×10^{-6} gm/cm^2 after 30 days, assuming a unity sticking fraction.

The presence of particulate matter in the vicinity of the spacecraft has been observed on all manned space missions. Also, many unmanned spacecraft have observed "false stars" which turned out to be particles that came from the spacecraft. The concern from the potential scientific users is twofold: the occasional large particle that moves through the field of view and produces an unwanted signal, and the possible production of a cloud of extremely fine particles that scatter sunlight and increase the background brightness.

Infrared astronomy is one of the disciplines most troubled by the sporadic particles. The 1.5-meter cryogenic infrared telescope can detect the blackbody radiation from a slow moving 5-micron particle at a distance of several kilometers. An occasional particle can be identified and removed from the data, but the process is time consuming and results in a partial data loss. If such occurrences were frequent, the data loss could become significant. The CRDG criterion calls for fewer than one such particle entering a 1.5×10^{-5} steradian field of view per orbit.

The CRDG requirement limiting the production of unresolved particles is based on the rationale that the background brightness from scattered light should be no more than 10 percent of the natural sky background from wavelengths of 155 nm to 1000 nm. The natural background was measured in the ultraviolet through the visible by Witt and Lillie and is approximately equivalent to 10^{-13} $B_{\odot}$ in the ultraviolet and 6×10^{-14} $B_{\odot}$ in the visible. Therefore, the required background brightness is 10^{-14} $B_{\odot}$ in the ultraviolet and 6×10^{-15} $B_{\odot}$ in the visible. This is stated in Volume X as "a 20th magnitude star per square arc second in the ultraviolet region." This is equivalent to 10^{-12} $B_{\odot}$.

To limit the number of particles carried into orbit from ground operations, cleanliness precautions in the form of HEPA filtered purge gas and controlled work discipline are exercised during ground activities. Volume X requires that payload surfaces be kept visibly clean during this operation. The CRDG requested the additional requirement that a 100K or better environment be maintained at all times and purge gas be used to produce no more than 10^{-6} gm/cm^2 nonvolatile residue (NVR) on the surfaces. The preceding contamination control requirements are summarized in Table 1. An excellent summary review of Space Shuttle-induced contamination concerns as well as specific effects of this environment on a sensitive infrared telescope has been given by Simpson and Witteborn.[6] Leger, Jacobs, and Ehlers have discussed Space Shuttle contamination analysis and control.[7]

3.0 DESCRIPTION OF IECM INSTRUMENTS

The IECM instrumentation was chosen or developed by the Space Sciences Laboratory, Marshall Space Flight Center, to meet the contamination level measurement requirements previously outlined. With the exception of infrared background radiation, which requires a cryogenically cooled infrared radiometer, the IECM instrumentation has the capability to verify the Space Shuttle specified contamination levels. Table 2 summarizes instrument performance specifications.

3.1 Humidity Monitor and Dewpointer

Two types of humidity detectors are used. One is a bulk detector called a Brady Array developed by Thunder Scientific. It responds to the presence of H_2O molecules in a specially prepared crystalline lattice with interstitial spaces through which these molecules can drift freely. The Brady Array can be

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6. Simpson, J. P. and Witteborn, F.C., Effect of the Shuttle contaminant environment on a sensitive infrared telescope, Applied Optics 16 (No. 8): 2051-2073 (1977).

7. Leger, L.; Jacobs, S.; and Ehlers, H.K.F., Space Shuttle contamination overview, Proc. Institute of Environmental Sciences (February 1978).

TABLE 1. SUMMARY OF CONTAMINATION SPECIFICATIONS AND MEASUREMENTS

REQUIREMENTS PRELAUNCH THROUGH ASCENT		
CONTAMINATION SPECIFICATION	SPEC. REF.	MEASUREMENT REQUIRED
AIR TEMPERATURE $70^{o} + 5^{o}$F	A, B	TEMPERATURE AND HUMIDITY
HUMIDITY 30–50%	A, B	TEMPERATURE AND HUMIDITY
PURGE GAS CLASS 100, GUARANTEED CLASS 5000, LESS THAN 15 PPM HYDROCARBONS	A, B	TRACE GAS ANALYSIS AEROSOL COUNT AND SIZE DISTRIBUTION
PURGE GAS PRODUCE LESS THAN 10^{-6} gm/cm^2 CONDENSIBLES ON SURFACES	B	NON–VOLATILE RESIDUE (NVR) DEPOSITION
CONTROL WORK DISCIPLINE TO MAINTAIN SURFACE CLEANLINESS AT LEVEL 300 A (VISIBLY CLEAN WITH LESS THAN 10^{-6} gm/cm^2 NVR)	A, B	AEROSOL COUNT AND SIZE DISTRIBUTION DUST FALL MEASUREMENTS NON–VOLATILE RESIDUE NVR DEPOSITION
MAINTAIN PARTICLE COUNT LESS THAN 100K IN VICINITY OF P/L	B	AEROSOL COUNT AND SIZE DISTRIBUTION

REFERENCES:
A. JSC 07700, VOL. X, PARAGRAPHS 3.6.12.2.4.1–.5
B. CRDG REQUIREMENTS DOCUMENT, PARAGRAPHS 4.1.2–.10

TABLE 1. (Concluded)

REQUIREMENTS ON ORBIT		
CONTAMINATION SPECIFICATIONS	SPEC REF.	MEASUREMENT REQUIRED
MOLECULAR COLUMN DENSITY LESS THAN		
10^{12} H_2O/cm^2	A	MOLECULAR COLUMN DENSITY
10^{11} $H_2O + CO_2/cm^2$	B	
10^{13} $N_2 + O_2/cm^2$	B	
10^{10} OTHER MOLECULES/cm^2		
SCATTERED/EMISSION LIGHT BACKGROUND LESS THAN		
m_u = 20 STAR/SEC^2 (10^{-12} BO IN U.V.)	A	BACKGROUND SPECTRAL INTENSITY
$10^{-14.2}$ BO IN VISIBLE	B	
$10^{-14.0}$ BO IN ULTRAVIOLET	B	
10^{-11} WATTS/m^2/sr/nm $\lambda < 30\ \mu$	B	
10^{-10} WATTS/m^2/sr^1/nm $\lambda > 30\ \mu$	B	
FEWER THAN ONE 5 μ PARTICLE PER ORBIT IN 1.5 X 10^{-5} STERADIAN FIELD–OF–VIEW	A, B	PARTICLE SIZE AND VELOCITY DISTRIBUTION
MOLECULAR RETURN FLUX SUCH THAT:		
$H_2O < 10^{12}$ MOLECULES/cm^2/sec	A	MOLECULAR RETURN FLUX
DEPOSITION 10^{-7} gm/cm^2 30 DAYS 0.2 sr ON 300°K SURFACE	B	MOLECULAR DEPOSITION ON AN AMBIENT SURFACE
DEPOSITION 10^{-5} gm/cm^2/30 DAYS 2 π sr ON 300°K SURFACE	B	MOLECULAR DEPOSITION ON AN AMBIENT SURFACE
DEPOSITION 10^{-5} gm/cm^2/30 DAYS 0.1 sr ON 20°K SURFACE	B	MOLECULAR DEPOSITION ON A CRYOGENIC SURFACE
DEGRADATION OF OPTICS 1%	A	DEGRADATION OF OPTICAL SURFACES

REFERENCES: A. JSC 07700, VOL. X, PARAGRAPH 3.6.12.2.4.6
B. CRDG REQUIREMENTS DOCUMENT, PARAGRAPH 4.2

TABLE 2. SUMMARY OF MEASUREMENT REQUIREMENTS AND IECM INSTRUMENTATION PERFORMANCE

MEASUREMENT REQUIRED	INSTRUMENT	REQUIRED PERFORMANCE (PREDICTED PERFORMANCE)
TEMPERATURE AND HUMIDITY	BRADY ARRAY	MEASURE: R.H. 0. – 100% ± 2% AIR TEMP. 0-70°C ± 1°C (WILL MEET REQUIREMENT)
	DEWPOINTER	MEASURE D. P., 0.-40°C ± .5°C (WILL MEET REQUIREMENT)
TRACE GAS ANALYSIS	AIR SAMPLER SYSTEM	CONTINUOUS – DETECT & IDENTIFY TRACE CONTAMINANTS IN < 1 PPM FROM LARGE SAMPLE VOLUME (WILL MEET REQUIREMENT)
		GRAB–DETECT SPECIFIC REACTIVE CONTAMINANTS IN SMALL SAMPLE TAKEN AT REDUCED PRESSURE (WILL MEET REQUIREMENT)
AEROSOL COUNT AND SIZE DISTRIBUTION	CASCADE IMPACTOR	MEASURE AEROSOL CONTENT IN RANGES FROM 0.3 – 1; 1–5, 5 MICRONS IN CLASS 100–100K ENVIRONMENT (WILL MEET REQUIREMENT)
NON–VOLATILE RESIDUE DEPOSITION	CASCADE IMPACTOR (NVR DETECTOR)	DETECT MOLECULAR DEPOSITION WITH 10^{-7} gm/cm^2 RESOLUTION ($\sim 10^{-9}$ gm/cm^2)

TABLE 2. (Continued)

MEASUREMENT REQUIRED	INSTRUMENT	REQUIRED PERFORMANCE (PREDICTED PERFORMANCE)
DUST FALL	OPTICAL EFFECTS MODULE (OEM)	MEASUREMENT PRESENCE OF DUST AT LEVEL 300 SURFACE CLEANLINESS (WILL MEET REQUIREMENT)
MOLECULAR COLUMN DENSITY	COLLIMATED MASS SPECTROMETER	MEASURE $10^8 \cdot 10^{17}$ MOLECULES /cm^2/sec/.1 sr FROM 2–150 AMU ($10^8 \cdot 10^{15}$ MOLECULES/cm^2/sec/.1 sr FROM 2–150 AMU)
BACKGROUND SPECTRAL INTENSITY	CAMERA/PHOTOMETER	MEASURE TO $10^{-14.2}$BO IN VISIBLE AND NEAR U. V. (WILL MEET REQUIREMENT)
	NONE	MEASURE IN BACKGROUND 10^{-11} WATT/m^2/sr/nm,$\lambda < 30\ \mu$ 10^{-10} WATT/m^2/sr/nm,$\lambda > 30\ \mu$ (NONE)
PARTICLE SIZE AND VELOCITY DIST.	CAMERA/PHOTOMETER	DETECT AND MEASURE PARTICLES 5μ DIA. MOVING AT 1 m/sec. ($\sim 10\ \mu$ DIA. AT 1m/sec)
MOLECULAR RETURN FLUX	COLLIMATED MASS SPECTROMETER	MEASURE 10^{10} MOLECULES/cm^2/sec FROM 2 – 150 AMU (WILL MEET REQUIREMENT)

TABLE 2. (Concluded)

MEASUREMENT REQUIRED	INSTRUMENT	REQUIRED PERFORMANCE (PREDICTED PERFORMANCE)
MOLECULAR DEPOSITION ON AMBIENT SURFACE	CASCADE IMPACTOR (NVR) DETECTOR	MEASURE MOLECULAR DEPOSITION IN AMBIENT SURFACE WITH RESOLUTION OF 10^{-9} grams/cm^2
	TEMPERATURE–CONTROLLED QUARTZ CRYSTAL MICRO–BALANCE (TQCM)	PROVIDE +80°C TO −50°C ± 1°C CONTROL OF COLLECTING SURFACE. MEASURE MOLECULAR DEPOSITION WITH 10^{-9} gram/cm^2 RESOLUTION
	PASSIVE SAMPLE ARRAY (PSA)	MEASURE TOTAL DEPOSITION (ALL ABOVE WILL MEET REQUIREMENT)
MOLECULAR DEPOSITION AT CRYOGENIC TEMPERATURES	CRYOGENIC QUARTZ CRYSTAL MICRO–BALANCE (CQCM)	RADIATIVELY COOL COLLECTOR TO 130°K. DETECT DEPOSITION WITH 10^{-9} gm/cm^2 RESOLUTION (WILL MEET REQUIREMENT)
DEGRADATION OF OPTICAL SURFACES	OPTICAL EFFECT MODULE (OEM)	MEASURE CHANGE IN U. V. TRANSMISSION TO 1% AS FUNCTION OF TIME.
		MEASURE DIFFUSE REFLECTION CHANGE TO 1% AS A FUNCTION OF TIME.
	PASSIVE SAMPLE ARRAY (PSA)	MEASURE TOTAL CHANGE (ALL ABOVE WILL MEET REQUIREMENT)

exposed to extreme temperatures and vacuum environment without impairing its ability to sense water. There are no known interferences that are sensed as H_2O, and it appears to be resistant to all major contaminants.

A thermistor is contained in the array to provide temperature data and to convert the measurements to relative humidity. The instrument can sense a 0.1 percent change in humidity, but hysteresis and thermal compensation limit the overall accuracy to ±2 percent over the entire temperature range.

The second system is an EG&G Dewpointer that actually measures the dew-point temperature. This is accomplished by servo controlling a thermoelectrically cooled mirror to the dew point. The mirror is illuminated by a light-emitting diode, and the specular and scattered light components are measured by photodiodes. The difference signal from the two detectors is the error signal. In this manner, the mirror is always driven to the temperature of incipient condensation. The dew-point temperature is measured to an accuracy of ±0.5°C, but the response time is 10 to 20 seconds.

The two instruments are complementary in that the dew-point measurement is inherently more accurate than the Brady Array and is better suited for static situations where little time resolution is necessary. On the other hand, the Brady Array is required to track the rapidly changing humidity associated with descent where it is important to know the moisture content as a function of altitude.

Both instruments are commercial items that have been fairly widely used. The Brady Array is primarily a laboratory- and field-use instrument. A small development effort was required to package the detector and associated electronics as a flight instrument. The EG&G Dewpointer was successfully flown on Skylab, and spare flight hardware is being used.

3.2 Air Sampler

Several approaches using mass spectrographs and gas chromatograph/mass spectrographs (GC/MS) with suitable inlet systems were considered for trace gas analysis. However, because of the cost and complexity of such flight systems, it was decided to sacrifice real-time readout capability and use post-flight analysis for this function.

The Air Sampler system, shown schematically in Figure 3, consists of five sampling bottles (one for ground operation, three for ascent, and one for descent) connected to a pumped manifold. Two positive displacement air pumps, shared with the Humidity Monitor and Dewpointer, are connected in parallel to the manifold. Bottle position one is used for ground operations to detect condensibles to 10 ppb or less. This bottle is manually uncapped and capped for operation and removal. Position one is also used for condensible collection during descent and post-landing. Condensibles during ascent are collected by the bottle in position two. Bottles in positions three and four are for detection of HCl combustion products during ascent using grab sampling (opening of evacuated bottle) and air pumping, respectively. Position five bottle is for sampling nitrogen compounds during descent. A summary of air sampling bottle operations, sensitivities, and adsorbers is given in Table 3.

Analysis of samples will be done in the laboratory using GC/MS techniques.

3.3 Cascade Impactor

The aerosol count in the ambient air will be measured by a Celesco Industries 3-stage cascade impactor (Figure 4) with special polymeric-coated quartz crystals serving as impactor plates. Ambient air is drawn in by a small pump at the rate of 250 ml/min, passed through a small orifice, and impinged against the measuring crystal. The special polymer serves to retain the particles on the surface and ensures that they are coupled with the vibrational motion of the quartz crystal. Viscous forces tend to entrain the particle in the air stream, and centrifugal forces tend to throw the particle onto the impactor surface. Depending on the air flow and spacing, particles larger

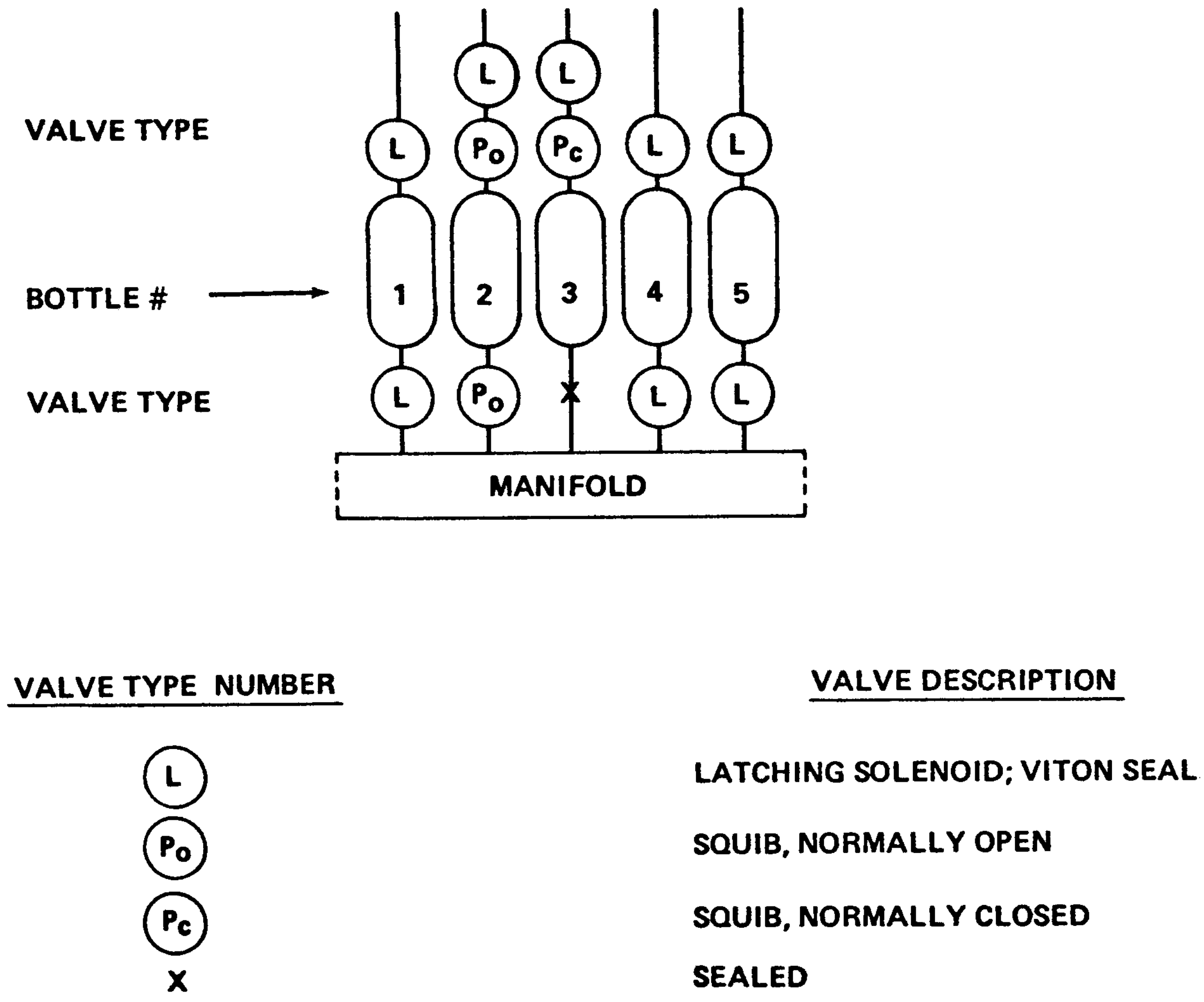

Figure 3. Schematic of Air Sampler bottles and valves.

TABLE 3. AIR SAMPLING BOTTLE CHARACTERISTICS

BOTTLE LOCATION NUMBER**	PRIMARY SAMPLING FUNCTION	ESTIMATED SENSITIVITIES	VALVE TYPES USED	BOTTLE CONTENTS
1	A. CONDENSIBLES, GROUND OPERATIONS	10 PPB OR LESS	NONE (MANUALLY CAPPED)	TENAX GC, SPHEROCARB, 400 mg EACH IN TANDEM
	B. CONDENSIBLES, DESCENT AND POSTFLIGHT PRIOR TO ACCESS	ALTITUDE DEPENDENT 10 PPB TO PPM	LATCHING SOLENOID	TENAX GC, SPHEROCARB, ~ 75 mg EACH IN TANDEM
2.	CONDENSIBLES ASCENT	ALTITUDE DEPENDENT	TWO PYRO N. O. AND LATCHING SOLENOID	TENAX, GC, SPHEROCARB ~ 75 mg EACH IN TANDEM
3.	HC1, GRAB SAMPLING	10 ± 5 PPM @ 1 TO 5 TORR	PYRO N. C., LATCHING SOLENOID	Ag2 0 COATED PLATLETS
4.	HC1, ASCENT	10 ± 5 PPM @ 1 TO 5 TORR	TWO LATCHING SOLENOIDS	Ag2 0 COATED PLATLETS
5.	NITROGEN COMPOUNDS, DESCENT	10 + 5 PPM @ 1 TO 5 TORR	TWO LATCHING SOLENOIDS	RUTHENIUM COMPOUND COATED PLATLETS

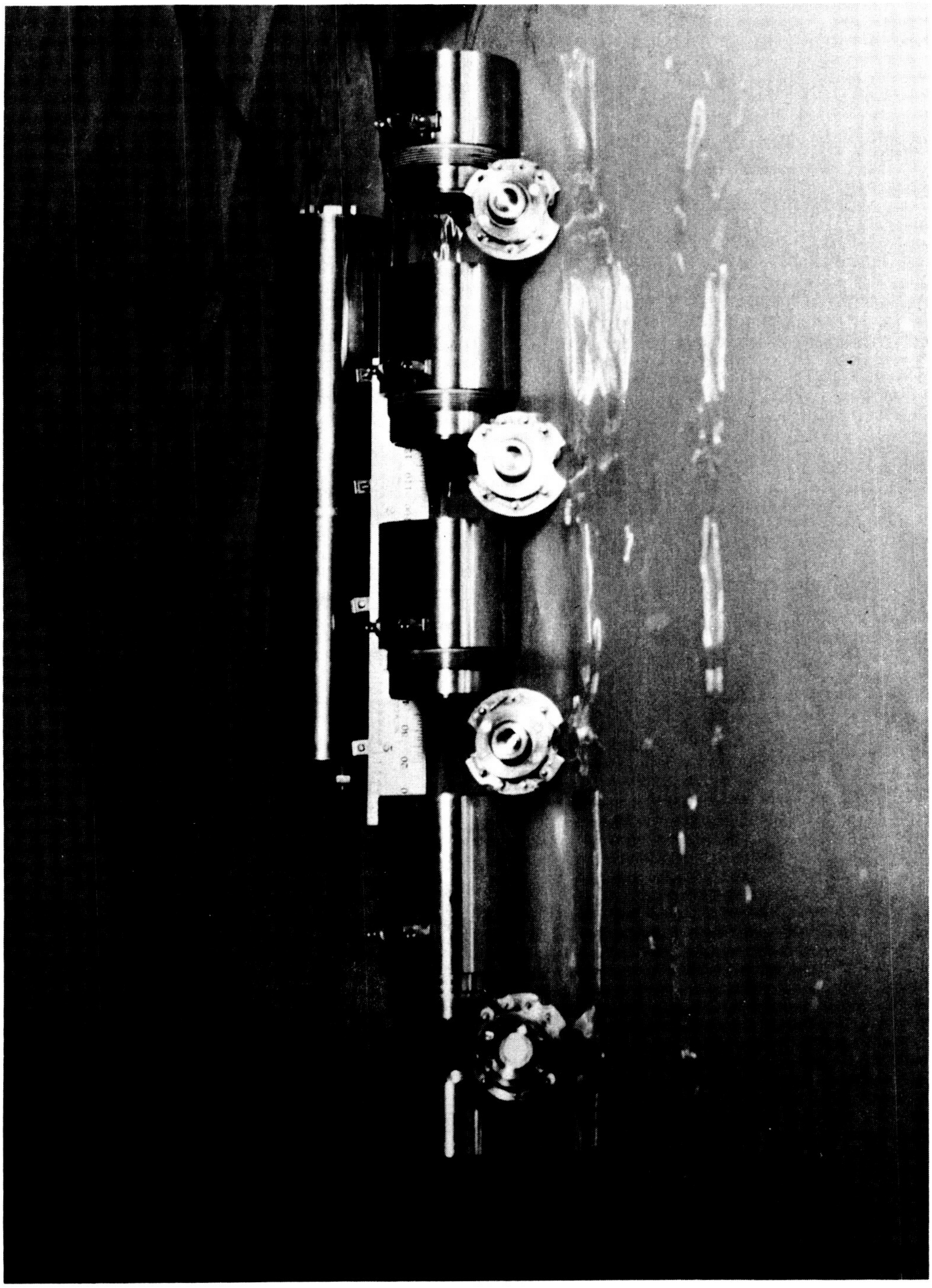

Figure 4. Cascade impactor.

than a certain radius will be imbedded in the polymeric coating on the crystal; their mass is measured by noting the change in oscillation frequency. The three stages are configured to measure particles from 0.3 to 1.0 micron, 1.0 to 5.0 microns, and 5.0 to 25.0 microns. One particular advantage of this type of detector is that the particles are retained and can be analyzed post-flight.

The system can detect a change on the order of 10^{-9} gram deposited, which corresponds to a 10-micron particle. In a class 100 environment, 2 days may be required to accumulate a detectable quantity of 0.3- to 1.0-micron particles, whereas approximately 3 hours are required to accumulate a detectable quantity of 5- to 25-micron particles. In a class 100K environment, accumulation times of only minutes are required to detect measurable changes. The crystals can accumulate several tens of micrograms before saturation. In a class 100K environment, the 5- to 25-micron section will collect 9 micrograms per day and will saturate in 2 to 4 days.

The cascade impactor is a variation of a commercial unit made by Celesco Industries. A flight prototype is being flown due to lack of funds to further develop this instrument.

3.4 Optical Effects Module

The Optical Effects Module (OEM) (Figure 5) built by Advanced Kinetics, Inc., consists of a monochromatic (253.65 nm light source, focussing and collecting optics, a rotatable sample carousel, and detectors. The OEM provides the IECM with the capability to monitor optical degradation of typical window materials due to both particulates and condensible molecular species. Six sample positions on the carousel allow three samples to be exposed at all times except for measurement. Two samples, plus an open position for calibration, remain inside the OEM housing for monitoring internal contamination. As the samples are periodically sequenced into the measurement

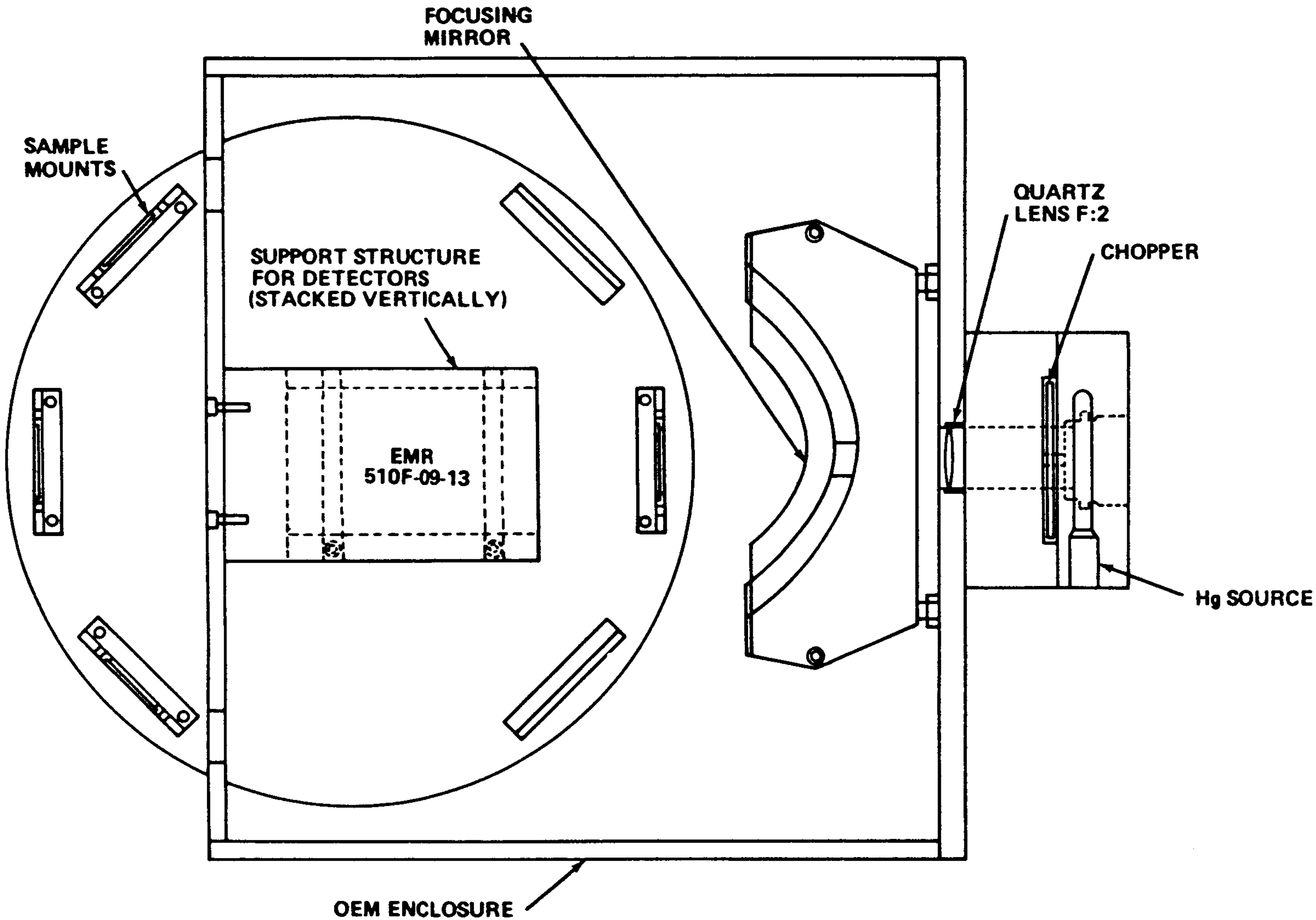

Figure 5. Optical Effects Module.

position, two photomultiplier detectors monitor specular transmittance and diffuse reflectance to a precision of 1 percent.

The nominal repetitive operation will allow approximately 7 minutes exposure and 1.3 minutes for measurements.

3.5 Passive Sample Array

The Passive Sample Array (PSA) consists of 8 sample trays containing 6 samples each, for a total of 48 samples (Figure 6). Each tray may be easily removed from its mounting, providing the capability of quick change out for laboratory analysis of changes of optical properties. The PSA was built at the Marshall Space Flight Center and is a modified version of a similar "witness" sample experiment on the Apollo Telescope Mount.

3.6 Mass Spectrometer

The IECM mass spectrometer is a quadrupole type developed by the University of Michigan for the Atmosphere Explorer Neutral Atmospheric Composition Experiment and is shown in Figure 7. It covers a mass range of 2 to 150 AMU with adjustable sweep rates and selectable mass range and stops. The flux range is 10^{8} to 10^{15} molecules cm^{-2} sec^{-1} 0.1 sr^{-1} with a sensitivity of 2×10^{-3} count sec^{-1} $particle^{-1}$ cm^{-3} with adjacent peak contribution of 10^{-3}.

The instrument contains a gettering collimator system to provide a collection cone of 0.1 sr. The collimator and spectrometer head are sealed from atmospheric contamination until on-orbit conditions exist and is resealed for re-entry to minimize refurbishment between flights. A gas release system is also incorporated to provide a tagged collimated gas for on-orbit calibration.

3.7 Camera/Photometer

The background intensity will be measured in the visible and near ultraviolet by an automatic camera/photometer system built by Epsilon Corporation (Figure 8). The system consists of two 16 mm Bolex movie cameras

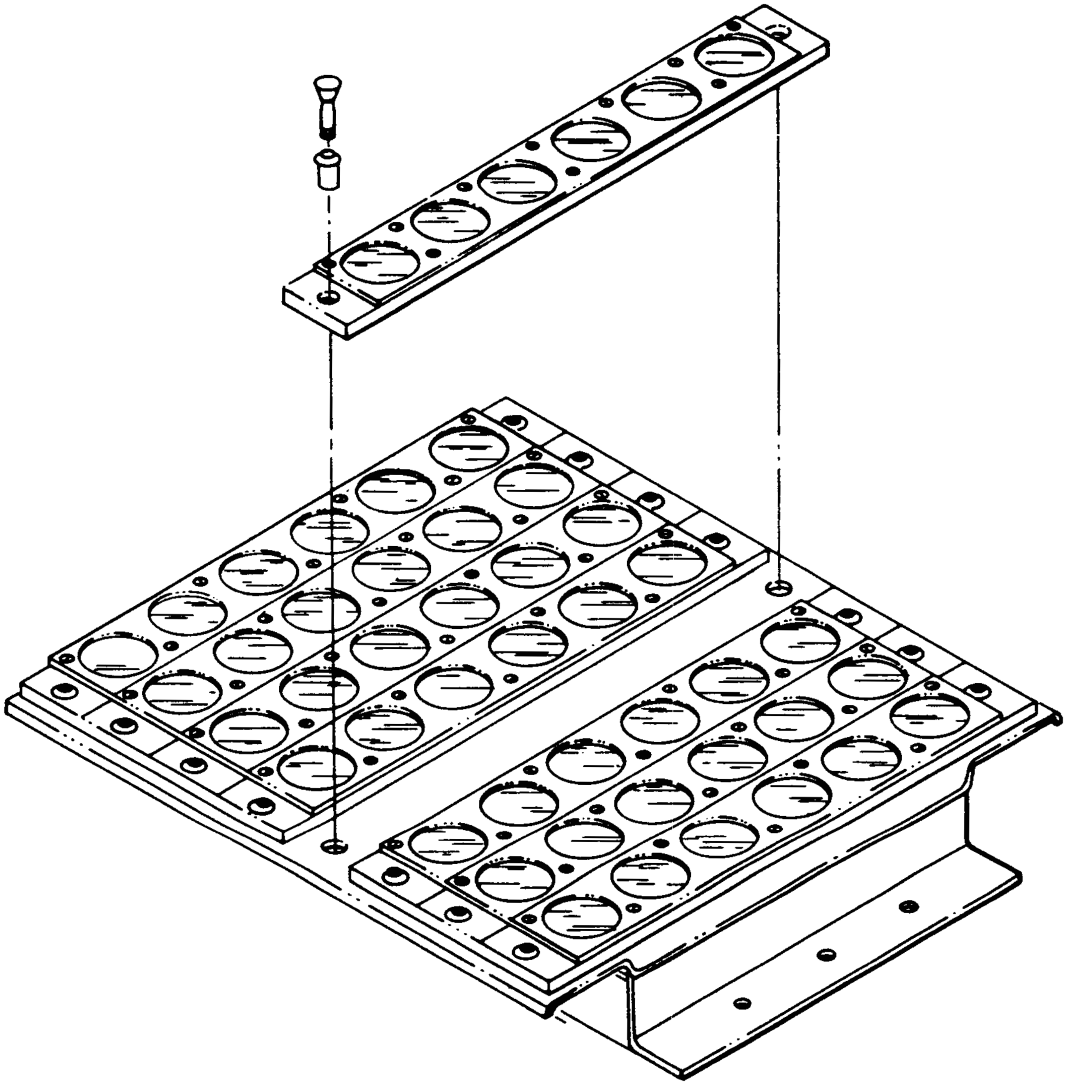

Figure 6. Passive Sample Array.

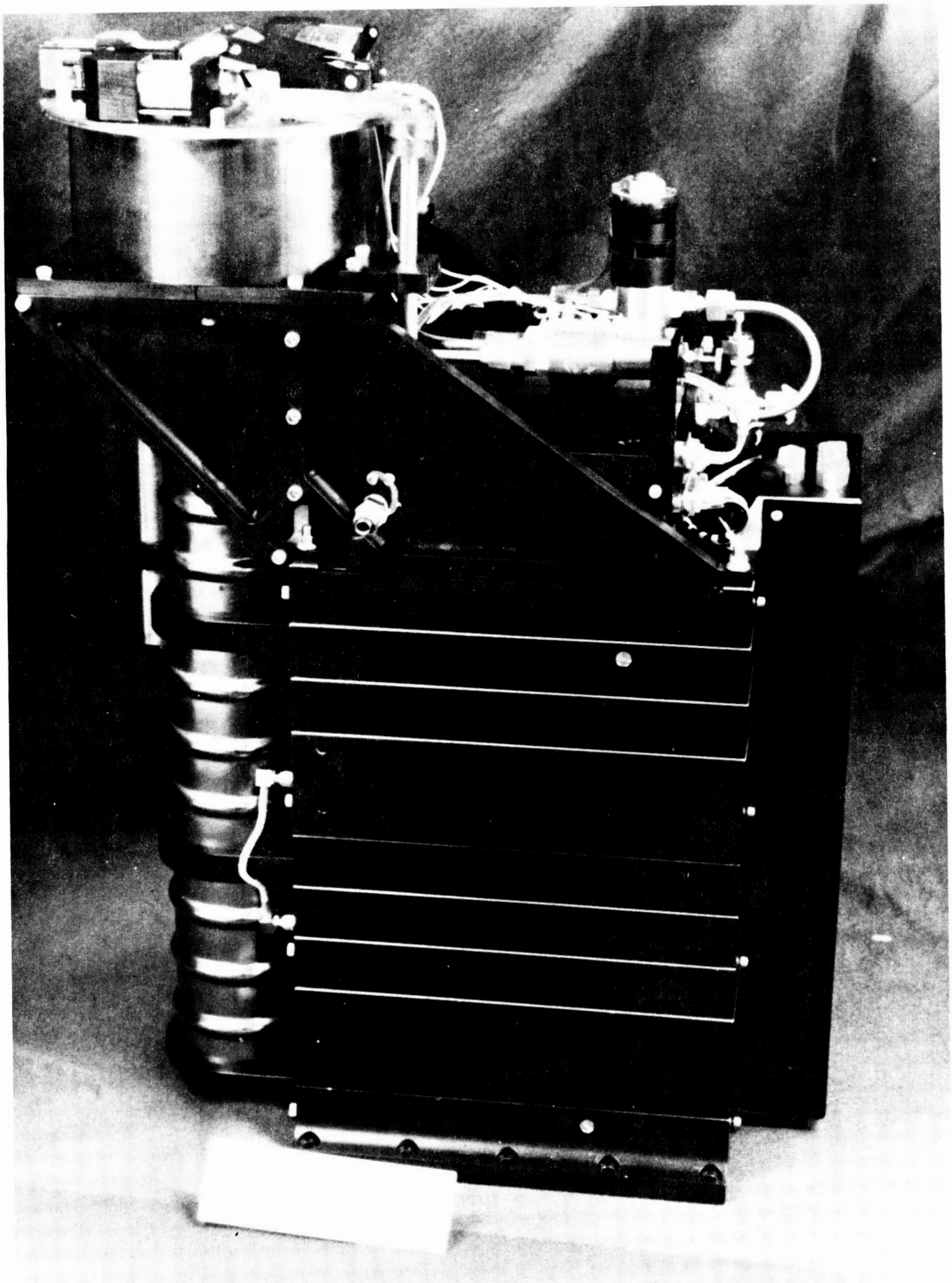

Figure 7. Mass spectrometer.

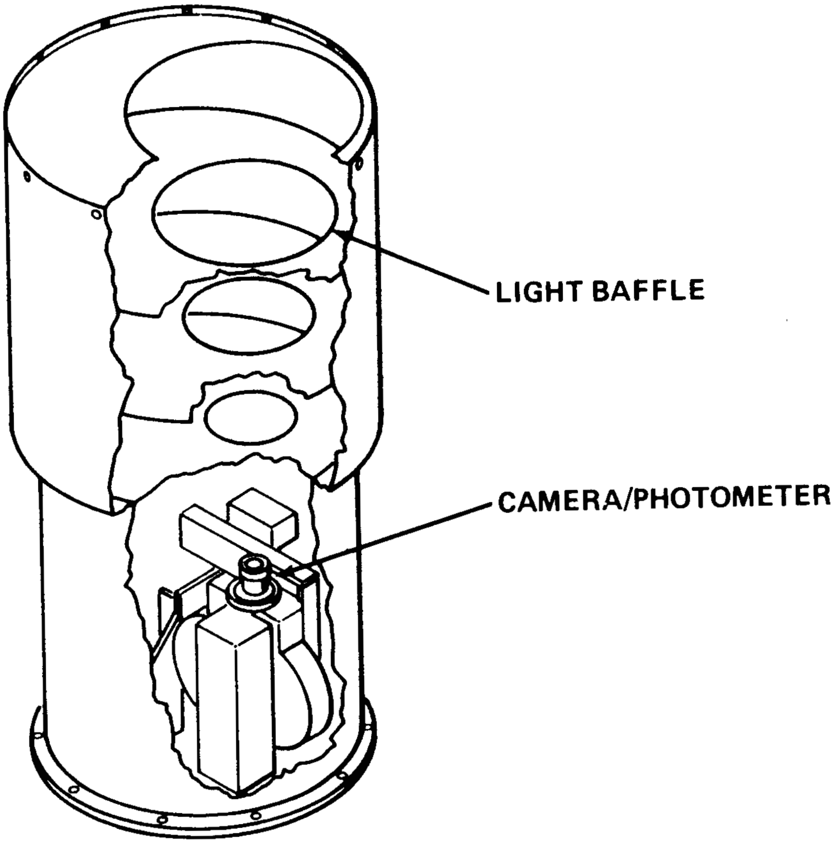

Figure 8. Camera/Photometer.

with 10 mm, f/1.9 Switar lenses and 4000 frame magazines. The film is advanced every 150 sec after a start command. The shutter is controlled by a photomultiplier photometer that integrates the incident light and closes the shutter when a predetermined exposure has been reached. This exposure value is chosen to give a film density just above the knee of the D-log E curve. This allows a measurement of the background without degradation of any particle tracks. The exposure time and the experiment elapsed time are annotated on the edge of the film.

The field of view of each camera/photometer is 20° in the vertical direction, providing stereo capability to define the velocity and direction of particles within the near field of the spacecraft.

3.8 Temperature-Controlled Quartz Crystal Microbalance

The Temperature-Controlled Quartz Crystal Microbalance (TQCM) instrument built by Faraday Laboratories, Inc., consists of a control unit with five sensor heads (Figure 9) mounted on the sides, ends, and top of the IECM package. Each sensor head consists of a QCM sensor and a two-stage bismuth-telluride thermoelectric device which uses the Peltier effect to heat and cool the sensor to the commanded temperature over the range of 80°C to approximately -60°C. The 80°C temperature is used for vaporization or "clean-up" of the quartz crystal surface, while the colder temperatures are used to collect condensibles.

The sensors have a field of view of approximately 120° and the sensitivity to measure mass changes of approximately 1×10^{-9} gm up to a total mass of approximately 1×10^{-4} gm.

3.9 Cryogenic Quartz Crystal Microbalance

The Cryogenic Quartz Crystal Microbalance (CQCM) (Figure 10), also built by Faraday Laboratories, Inc., consists of two passive thermally controlled QCM sensors isolated from the IECM structure. During normal orbital

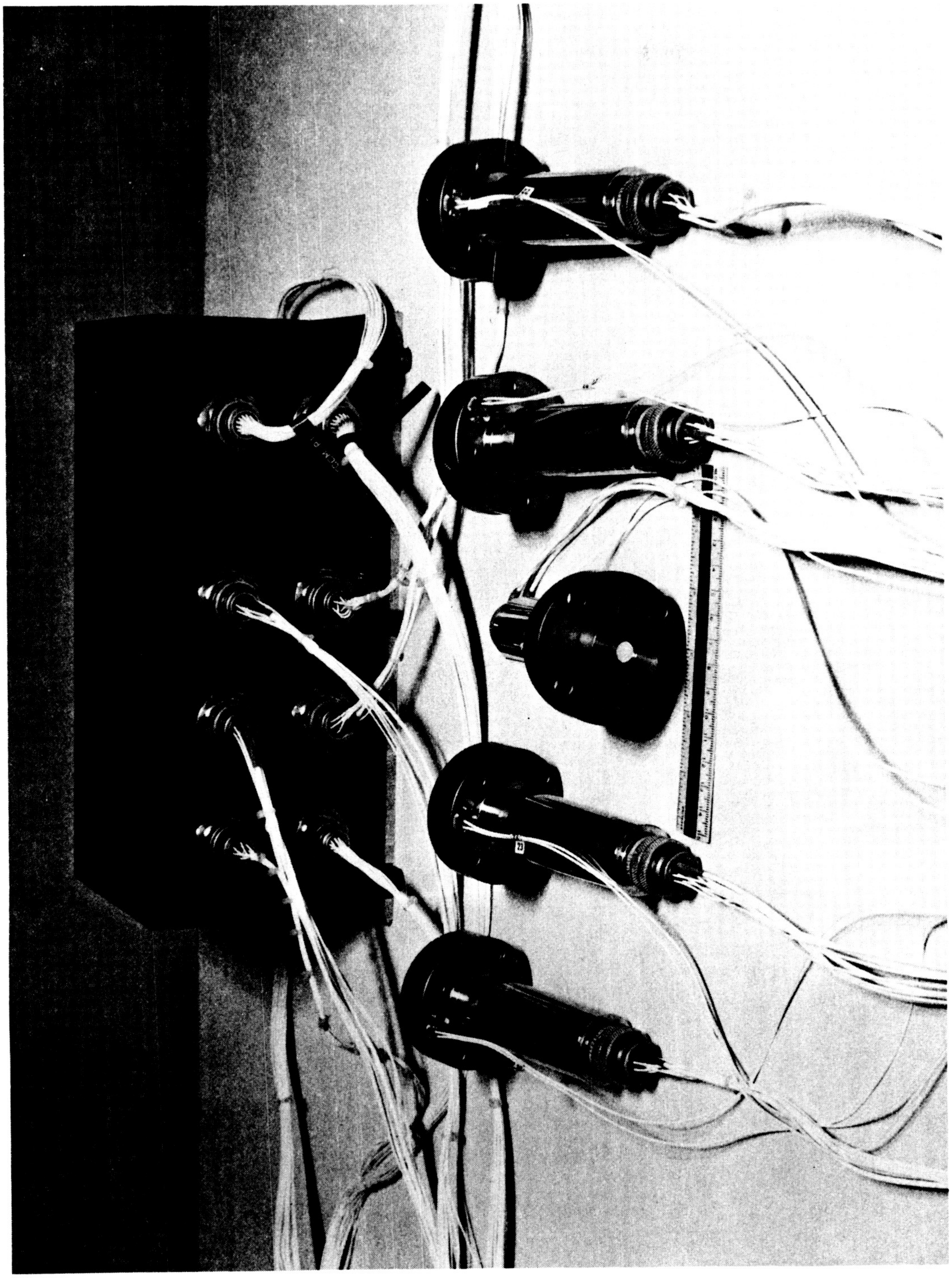

Figure 9. Temperature-Controlled Quartz Crystal Microbalance.

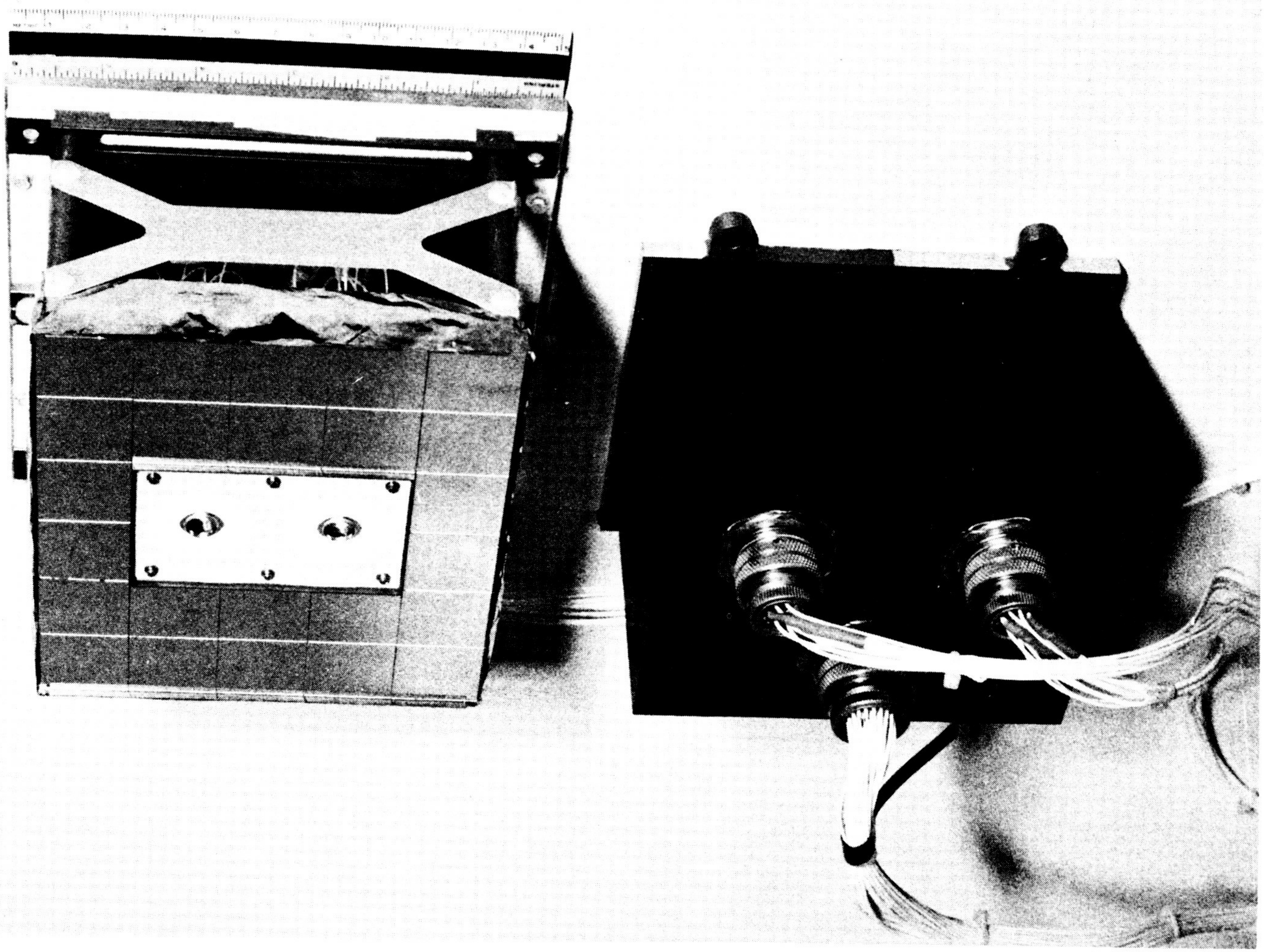

Figure 10. Cryogenic Quartz Crystal Microbalance.

modes the sensors nominally would be at a lower temperature than the IECM ambient. However, during "cold soak" portions of the Orbiter operations, the CQCM is designed to cool down to below -133°C where molecular water will begin to condense. The two sensors are designed to passively cool down and actively heat up at slightly different rates such that differential condensation and evaporation rates may be detected. A heater is incorporated to provide sensor cleaning capability.

4.0 LONG DURATION EXPOSURE FACILITY IECM

The LDEF satellite to be launched by Space Shuttle will carry a small version of the IECM primarily to gather contamination data on an off-line buildup of a Space Shuttle payload and on deployment operations.

The LDEF IECM (Figure 2) is instrumented with the Optical Effects Module, Passive Sample Array, Temperature-Controlled Quartz Crystal Microbalance with five sensors, and a Cryogenic Quartz Crystal Microbalance. Like the larger version, the LDEF IECM is self-contained. Batteries supply power for the instruments and data system for some 20 hours after deployment, although power is obtained from the Space Shuttle Orbiter before deployment.

The LDEF will be retrieved after approximately 9 months in space.

5.0 IECM OPERATIONS

The IECM will monitor contamination levels during prelaunch operations at Kennedy Space Center. At present, it is planned to obtain data in the Orbiter Processing Facility (OPF), the Vertical Assembly Building (VAB) once the Orbiter is mated with the mobile launch platform, and on the launch pad in the Payload Changeout Room (PCR).

The prime measurements during prelaunch operations will be temperature, humidity, aerosols, nonvolatile condensibles, and trace gases utilizing the Brady Array, Dewpointer, Cascade Impactor, Air Sampler, Optical

Effects Module, and Passive Sample Array (Table 1). These same instruments will be operating during ascent, descent, and post-landing, with the exception of the Optical Effects Module on ascent and with the addition of the Temperature-Controlled Quartz Crystal Microbalance and Cryogenic Quartz Crystal Microbalance.

The prime measurements during ascent and descent will be the same as prelaunch with the appropriate sampling rate and Air Sampler sequencing changes. For post-landing measurements the IECM will operate for approximately 1 hour on internal batteries, measuring effects of temperature heat-up from re-entry and the purge gas hookup which will occur approximately 15 minutes after landing.

The prime measurements on-orbit will be concerned with particulate and gaseous contaminants that will be continuously emitted from the spacecraft and will be interacting with the space environment. The Mass Spectrometer, Camera/Photometer, Optical Effects Module, Passive Sample Array, Temperature-Controlled Quartz Crystal Microbalance, and Cryogenic Quartz Crystal Microbalance will be operating.

A special maneuver has been requested on several OFT flights to scan the spacecraft from the wake to ram with respect to its velocity vector to provide data on molecular collisional cross sections, utilizing the mass spectrometer and its gas release system.

The IECM measurements are time-coded to allow correlation with various spacecraft events such as spacecraft maneuvering, "hot soaks," "cold soaks," venting, etc.

5.1 Contamination Mapping

The Space Shuttle Remote Manipulator System (RMS) presents the opportunity to maneuver the IECM around the spacecraft to directly measure emitted contamination. The Marshall Space Flight Center has designed a release/attach mechanism for the IECM such that the IECM can be both mechanically and electrically removed from the payload bay at the RMS. The mapping maneuver will involve placing the IECM in various positions above the spacecraft to monitor ambient outgassing and off-gassing, Vernier control systems, and evaporator contamination levels. When this is accomplished, an RCS engines plume flow field survey will be made by a pressure gauge incorporated in the IECM for this purpose. At the end of these maneuvers the IECM will be reattached mechanically and electrically to the spacecraft and will resume its normal on-orbit contamination monitoring operations.

6.0 CONCLUSION

The Shuttle Induced Environment Contamination Monitor provides a method to verify the contamination environment associated with Space Shuttle and to obtain data on the adequacy of controls that are now imposed. These data will be used to verify and revise models now being used to predict contamination levels on various Space Shuttle/Spacelab missions.

REFERENCES

1. Anon., Final Report of the Space Shuttle Payload Planning Working Groups, Astronomy Volume 1, NASA/Goddard Space Flight Center, Greenbelt, Maryland (May 1973).

2. Space Science Board, Scientific Uses of the Space Shuttle, National Academy of Sciences, Washington, D. C. (1974).

3. Payload Contamination Control Requirements for Shuttle Transportation System (STS) Induced Environment, STS Payload Contamination Requirements Definition Group Report, NASA/Marshall Space Flight Center (July 1975).

4. Space Shuttle Program Level II Program Definition and Requirements, NASA/JSC-07700 Flight and Ground Systems Specification, Volume X, Revision B (August 1975).

5. Space Shuttle Program Level II Program Definition and Requirements, NASA/JSC-07700, Volume XIV, Revision E (July 1977).

6. Simpson, J. P. and Witteborn, F. C., Effect of the Shuttle contaminant environment on a sensitive infrared telescope, Applied Optics 16 (No. 8): 2051-2073 (1977).

7. Leger, L.; Jacobs, S.; and Ehlers, H. K. F., Space Shuttle contamination overview, Proc. Institute of Environmental Sciences (February 1978).